SECTION 2 - EQUIVALENT PROCEDURES FOR SUBSONIC JET POWERED AEROPLANES

The objective of a noise demonstration test is to acquire data for establishing an accurate and reliable definition of the aeroplane's noise characteristics under reference conditions (see Section 2.6 of Annex 16, Volume 1, for Chapter 2 aeroplanes and Section 3.6 for Chapter 3 aeroplanes). In addition, the Annex sets forth a range of test conditions and the procedures for adjusting measured data to reference conditions.

2.1 FLIGHT TEST PROCEDURES

The following methods have been used to provide equivalent results to Annex 16, Volume 1, Chapters 2 and 3 procedures for turbo-jet and turbo-fan powered aeroplanes.

2.1.1 **Flight path intercept procedures**

2.1.1.1 Flight path intercept procedures in lieu of full take-off and/or landing profiles described in paragraphs 9.2 and 9.3 of Appendix 1 or paragraphs 9.2 of Appendix 2 of Annex 16, Volume 1, have been used to meet the demonstration requirements of noise certification. The intercept procedures have also been used in the implementation of the generalised flight test procedures described in Section 2.1.2 of this manual. The use of intercepts eliminates the need for actual take-offs and landings (with significant cost and operational advantages at high gross mass) and substantially reduces the test time required. Site selection problems are reduced and the shorter test period provides a higher probability of stable meteorological conditions during testing. Aeroplane wear, and fuel consumption are reduced and increased consistency and quality in noise data are obtained.

2.1.1.2 Figure l(a) illustrates a typical take-off profile. The aeroplane is initially stabilised in level flight at a point A and continues to point B where take-off power is selected and a steady climb is initiated. The steady climb condition is achieved at point C, intercepting the reference take-off flight path and continuing to the end of the noise certification take-off flight path. Point D is the theoretical take-off rotation point used in establishing the reference flight path. If cutback power is employed, point E is the point of application of power cutback and F, the end of the noise certification take-off flight path. The distance TN is the distance over which the position of the aeroplane is measured and synchronised with the noise measurement at K.

2.1.1.3 For approach, the aeroplane usually follows the planned flight trajectory while maintaining a constant configuration and power until no influence on the noise levels within ten decibels of PNLTM. The aeroplane then carries out a go-around rather than continuing the landing (See Fig. 1(b)).

2.1.1.4 For the development of the noise-power-distance data for the approach case (see 2.1.2.1) the speed, and approach angle constraints imposed by Annex 16, Volume 1 in 2.6.2 and 3.6.3 and 3.7.5 cannot be satisfied over the typical ranges of thrust needed. For the approach case speed shall be maintained at 1.3 V_S + 19 km/h (1.3 V_S + 10 kt) to within ±9 km/h or ±5 kt and flyover height over the microphone maintained at 400 ft ±100 ft. However the approach angle at the test thrust shall be that which results from the aircraft conditions, ie. mass, configuration, speed and thrust.

2.1.1.5 The flight profiles should be consistent with the test requirements of the Annex over a distance that corresponds at least to noise levels 10 dB below the maximum tone corrected Perceived Noise Level (PNLTM) obtained at the measurement points during the demonstration.

2.1.2 **Generalised flight test procedures**

The following equivalent flight test procedures have been used for noise certification compliance demonstrations.

2.1.2.1 *Derivation of noise, power, distance data*

2.1.2.1.1 For a range of powers covering full take-off and cut-back powers, the aeroplane is flown past lateral and under-flight-path microphones according to either the take-off procedures defined in paragraph 3.6.2 of Volume 1 of Annex 16 or, more typically, flight path intercept procedures described in Section 2.1.1 of this manual. ~~in accordance with paragraphs 3.6.2.1 c) d) of Annex 16, Volume 1.~~ Target test conditions are established for each sound measurement. These target conditions define the flight procedure, aerodynamic configuration to be selected, aeroplane weight, power, airspeed and, at the closest point of approach to the measurement location, height. Regarding choice of target airspeeds and variation in test weights, the possible combinations of these test elements may affect the aeroplane angle-of-attack or aeroplane attitude and therefore possibly the aeroplane sound generation or propagation geometry. The aeroplane angle-of-attack will remain approximately constant for all test weights if the tests are conducted at the take-off reference airspeed appropriate for each test weight. (As an example if the appropriate take-off reference airspeed for the aeroplane is V_2+15 kt set the target airspeed for each test weight at V_2+15 kt; the actual airspeed magnitude will vary according to each test weight but the aeroplane test angle-of-attack will remain approximately constant.) Alternatively, for many aeroplanes the aeroplane attitude remains approximately constant for all test weights if all tests are conducted at the magnitude of the take-off reference airspeed corresponding to the maximum take-off weight. (As an example if the approximate take-off reference airspeed for the aeroplane is V_2+15 kt set the target airspeed for each test weight at the magnitude of the V_2+15 kt airspeed that corresponds to the maximum take-off weight; the airspeed magnitude remains constant for each test weight and the aeroplane attitude remains approximately constant.) Review of these potential aeroplane sensitivities may dictate the choice of target airspeeds and/or test weights in the test plan in order to limit excessive changes in angle-of-attack or aeroplane attitude that could significantly change measured noise data. In the execution of each condition the pilot should “set up” the aeroplane in the appropriate condition in order to pass by the noise measurement location within the target height window, while maintaining target power and airspeed, within agreed tolerances, throughout the 10dB-down time period.

2.1.2.1.2 A sufficient number of noise measurements are made to enable noise-power curves at a given distance for both lateral and flyover cases to be established. These curves are extended either by calculation or by the use of additional flight test data to cover a range of distances to form the generalised noise data base for use in the noise certification of the "flight datum" and derived versions of the type and are often referred to as Noise-Power-Distance (NPD) plots(see Fig. 2). If over any portion of the range for the NPD plot the criteria for calculating the EPNdB given in paragraphs 9.1.2 and 9.1.3 of Appendix 2 of Annex 16, Volume 1, requires the use of the integrated procedure, this procedure shall be used for the whole NPD. The 90 per cent confidence intervals about the mean lines are constructed through the data (see paragraph 2.2 of Appendix 1). ~~This is repeated~~

Note: The same techniques can be used to develop NPD’s appropriate for the derivation of approach noise levels by flying over ~~for~~ an under flight path microphone for a range of approach powers using the speed and aeroplane configuration given in paragraph 3.6.3 of Annex 16, Volume 1, or more typically, flight test procedures described in 2.1.1 of this manual.

2.1.2.1.3~~2~~ Availability of flight test data for use in data adjustment, e.g. speed and altitude, should be considered in test planning and may limit the extent to which a derived version may be developed without further flight testing especially where the effects of airspeed on source noise levels become significant. The effects of high altitude test site location on jet noise source levels should also be considered in test planning. High altitude test site locations have been approved under conditions specified in Appendix 6 provided that jet noise source corrections are applied to the noise data. The correction method of Appendix 6 has been approved for this purpose.

2.1.2.1.4~~3~~ The take-off, lateral and approach noise measurements should be corrected to the reference speed and atmospheric conditions over a range of distances in accordance with the procedures described in Appendix 1 (Chapter 2 aeroplanes) or Appendix 2 (Chapter 3 aeroplanes) of Annex 16, Volume 1. The NPD plots can then be constructed from the corrected Effective Perceived Noise Level (EPNL), power and distance information. The curves present the EPNL value for a range of distance and engine noise performance parameters, (see Annex 16, Volume 1, paragraph 9.3.4.1 of Appendix 2). The parameters are usually the corrected low pressure rotor speed $N_1 \big/ \sqrt{q_{t_2}}$ or the corrected net thrust F_N/d_{amb} (see Fig. 2), where:

N_1 is the actual low pressure rotor speed;

q_{t_2} is the ratio of absolute static temperature of the air at the height of the aeroplane to the absolute temperature of the air for an international standard atmosphere (ISA) at mean sea level (ie. 288.15 °K);

F_N is the actual engine net thrust per engine; and

d_{amb} is the ratio of absolute static pressure of the ambient air at the height of the aeroplane to ISA air pressure at mean sea level (ie. 101.325 kPa).

2.1.2.1.5~~4~~ Generalised NPD data may be used in the certification of the flight tested aeroplane and derivative versions of the aeroplane type. For derived versions, these data may be used in conjunction with analytical procedures, static testing of the engine and nacelle or additional limited flight tests to demonstrate compliance.

2.1.2.2 *Procedures for the determination of changes in noise levels*

Noise level changes determined by comparison of flight test data for different developments of an aeroplane type have been used to establish certification noise levels of newly derived versions by reference to the noise levels of the "flight datum" aeroplane. These noise changes are added to or subtracted from the noise levels obtained from individual flights of the "flight datum" aeroplane. Confidence intervals of new data are statistically combined with the "flight datum" data to develop overall confidence intervals (see Appendix 1).

2.1.3 The determination of the lateral noise certification levels

2.1.3.1 Alternative procedures using two microphone stations located symmetrically on either side of the take-off reference track has proved to be effective in terms of time and costs savings. Such an arrangement avoids many of the difficulties encountered in using the more conventional multi-microphone arrays. The procedures consist of flying the test aeroplane at full take-off power at one (or more) specified heights above a track at right angles to and midway along the line joining the two microphone stations. However, when this procedure is used matching data from both lateral microphones for each fly-by should be used for the lateral noise determination; cases where data from only one microphone is available for a given run must be omitted from the determination. The following paragraphs describe the procedures for determining the lateral noise level for subsonic turbo-jet or turbo-fan powered aeroplanes.

2.1.3.2 Lateral noise measurements for a range of conventionally configured aeroplanes with under wing and/or rear-fuselage mounted engines with bypass ratio of more than 2, have shown that the maximum lateral noise at full power normally occurs when the aeroplane is close to 300 m (985 ft) or 435 m* (1,427 ft) in height during the take-off. Based on this finding it is considered acceptable to use the following as an equivalent procedure:

a) for aeroplanes to be certificated under Chapter 3 or Chapter 2 of Annex 16, Volume 1, two microphone locations are used, symmetrically placed on either side of the aeroplane reference flight track and 450 m or 650 m* from it;

b) for aeroplanes with engines having bypass ratios of more than 2, the height of the aeroplane as it passes the microphone stations should be 300 m (985 ft) or 435 m* (1,427 ft) and be no more than +100 m, -50 m (+328 ft, -164 ft) relative to this target height. For aeroplanes with bypass ratios of 2 or less it is necessary to determine the peak lateral noise by undertaking a number of flights over a range of heights to define the noise (EPNL) versus height characteristics. A typical height range would cover 60 m (200 ft) to 600 m (2000 ft) above the inter-section of a track at right angles to the line joining the two microphone positions and this line;

c) constant power, configuration and airspeed as described in paragraphs 3.6.2.1 a), 3.6.2.1 d), 2.6.1.2 and 2.6.1.3 of Annex 16, Volume 1, should be used during the flight demonstration;

d) adjustment of measured noise levels should be made to the acoustical reference day conditions and to reference aeroplane operating conditions as specified in Section 9 of Appendix 1 and 2 of Annex 16, Volume 1; and

e) to account for any possible asymmetry effects in measured noise levels, the reported lateral noise level for purposes of demonstrating compliance with the applicable noise limit of Chapter 3 or Chapter 2 of Annex 16, Volume 1, as applicable, should be the arithmetic average of the corrected maximum noise levels from each of the two lateral measurement points and compliance should be determined within the ±1.5 dB 90 per cent confidence interval required by the Annex (see paragraph 2 of Appendix 1 of this manual).

2.1.3.3 Lateral noise certification level determination has also been accomplished using multiple pairs of lateral microphones rather than only one pair of symmetrically located microphones. A sufficient number of acceptable data points, resulting from a minimum of six runs, must be obtained from sufficiently spaced microphone pairs to adequately define the maximum lateral noise certification level and provide an acceptable 90 per cent confidence interval.

2.1.4 **Take-off flyover noise levels with power cut-back**

* For Chapter 2 procedures.

Flyover noise levels with power cut-back may also be established without making measurements during take-off with full power followed by power reduction in accordance with paragraph 2.2.1 of this manual.

2.1.5 **Measurements at non-reference points**

2.1.5.1 In some instances test measurement points may differ from the reference measurement points specified in Annex 16, Volume 1, Chapters 2 and 3, paragraphs 2.3.1 and 3.3.1. Under these circumstances an applicant may request approval of data that have been adjusted from the actual measurements to represent data that would have been measured at the reference points in reference conditions.

2.1.5.2 Reasons for such a request may be:

a) to allow the use of a measurement location that is closer to the aeroplane flight path so as to improve data quality by obtaining a greater ratio of signal to background noise. Whereas Appendix 3 describes a procedure for removing the effects of ambient noise the use of data collected closer to the aeroplane avoids the interpolations and extrapolations inherent in the method;

b) to enable the use of an existing, approved certification data base for an aeroplane type design in the certification of a derivative of that type when the derivative is to be certificated under reference conditions that differ from the original type certification reference conditions; and

c) to avoid obstructions near the noise measurement station(s) which could influence sound measurements. When a flight path intercept technique is being used, take-off and approach noise measurement stations may be relocated as necessary to avoid undesirable obstructions. Sideline measurement stations may be relocated by distances which are of the same order of magnitude as the aeroplane lateral deviations (or offsets) relative to the nominal flight paths that occur during flight testing.

2.1.5.3 Approval has been granted to applicants for the use of data from non-reference noise measurement points provided that measured data are adjusted to reference conditions in accordance with the requirements of section 9 of Appendix 1 or 2 of Annex 16, Volume 1, and the magnitudes of the adjustments do not exceed the limitations in section 5.4 of Appendix 1 and paragraph 3.7.6 of Chapter 3 of the Annex.

2.1.6 **Atmospheric test conditions**

It has been found acceptable by certificating authorities to exceed the sound attenuation limits of Annex 16, Volume 1, Appendix 2, Section 2.2.2(c) when:

a) the dew point and dry bulb temperature are measured with a device which is accurate to ± 0.5 °C and are used to obtain relative humidity and when 'layered' sections of the atmosphere are used to compute equivalent weighted sound attenuations in each one-third octave band, sufficient sections being used to the satisfaction of the certificating authority; or

b) where the peak noy values at the time of PNLT, after adjustment to reference conditions, occur at frequencies of less than or equal to 400 Hz.

2.1.7 **Reference approach speed**

The reference approach speed is currently contained in 3.6.3.1(b) of Chapter 3 of Annex 16, Volume 1 as 1.3 V_S + 19 km/h (1.3 V_S + 10 kt). There is a change being made to the definition of stall speed, for airworthiness reasons, to alter the current minimum speed V_S definition to a stall speed during a 1-g manoeuvre (ie. a flight load factor of unity) V_{S1g}. In terms of the new definition the approach reference speed becomes 1.23 V_{S1g} + 19 km/h, (1.23 V_{S1g} + 10 kt) which can be taken as equivalent to the reference speed contained in Chapter 3.

~~2.1.8 **Anomalous wind conditions**~~

~~To avoid the adverse affects of atmospheric turbulence in scattering aircraft noise the following criteria have been adopted for noise certification flight test demonstrations. Each flight past the microphone is acceptable if the instantaneous indicated airspeed (IAS), obtained from the pilot's airspeed indicator is within ±3 per cent of the average airspeed between the 10 dB-down points for each microphone. However should the instantaneous airspeed exceed ±5.5 km/h (±3 kt) of the average airspeed over the 10 dB-down points and this is judged by the certificating authority representative on the flight deck to be due to turbulence, then the flight so affected should be rejected for noise certification purposes.~~

2.2 ANALYTICAL PROCEDURES

Analytical equivalent procedures rely upon available noise and performance data obtained from flight test for the aeroplane type. Generalised relationships between noise, power and distance (NPD plots see 2.1.2.1) and adjustment procedures for speed changes in accordance with the methods of Appendix 1 or 2 of Annex 16, Volume 1, are combined with certificated aeroplane aerodynamic performance data to determine noise level changes resulting from type design changes. These noise level increments are then applied to noise levels in accordance with paragraph 2.1.2.2 of this manual.

2.2.1 **Flyover noise levels with power cut-back**

Note: The "average engine" spool-down time should reflect a 1.0 second minimum altitude recognition lag time to account for pilot response.

2.2.1.1 Flyover noise levels with power cut-back may be established from the merging of PNLT versus time measurements obtained during constant power operations. As seen in Fig. 4(a) the 10 dB-down PNLT noise time history recorded at the flyover point may contain portions of both full power and cut-back power noise time histories. Provided these noise time histories, the average engine spool-down thrust characteristics and the aeroplane flight path during this period (See Fig. 4(b)), which includes the transition from full to cut-back power, are known, the flyover noise level may be computed.

2.2.1.2 Where the full power portion of the noise time history does not intrude upon the 10 dB-down time history of the cut-back power, the flyover noise levels may be computed from a knowledge of the NPD characteristics and the effect of the average spool-down thrust characteristics on the aeroplane flight path.

Note: To ensure that the full power portion of the noise time history does not intrude upon the 10 dB-down noise levels, $PNLTM_{after\ cutback} - PNLT_{before\ cutback} \geq 10.5\ dB$

2.2.2 **Equivalent procedures based on analytical methods**

Noise certification approval has been given for applications based on type design changes that result in predictable noise level differences including the following:

a) changes to the originally certificated take-off or landing mass which lead to changes in distance between the aeroplane and the microphone for the take-off case and changes to the approach power. In this case the NPD data may be used to determine the noise certification level of the derived version;

b) noise changes due to engine power changes. However, care should be taken to ensure that when NPD plots are extrapolated the relative contribution of the component noise sources to the Effective Perceived Noise Level remains essentially unchanged and a simple extrapolation of the noise/power and noise/distance curves can be made. Among the items which should be considered in extension of the NPD are:
   - the 90% confidence interval at the extended power;
   - aeroplane/engine source noise characteristics and behaviour;
   - engine cycle changes; and
   - quality of data to be extrapolated.

c) aeroplane engine and nacelle configuration and acoustical treatment changes, usually leading to changes in EPNL of less than one decibel. However, it should be ensured that new noise sources are not introduced by modifications made to the aeroplane, engine or nacelles. A validated analytical noise model approved by the certificating authority may be used to derive predictions of noise increments. The analysis may consist of modelling each aeroplane component noise source and projecting these to flight conditions in a manner similar to the static test procedure described in paragraph 2.3. A model of detailed spectral and directivity characteristics for each aeroplane noise component may be developed by theoretical and/or empirical analysis. Each component should be correlated to the parameter(s) which relates to the physical behaviour of source mechanisms. The source mechanisms, and subsequently the correlating parameters, should be identified through use of other supplemental tests such as engine or component tests. As described in paragraph 2.3 an EPNL representative of flight conditions should be computed by adjusting aeroplane component noise sources for forward speed effects, number of engines and shielding, reconstructing the total noise spectra and projecting the total noise spectra to flight conditions by accounting for propagation effects. The effect of changes in acoustic treatment, such as nacelle lining, may be modelled and applied to the appropriate component noise sources. The computation of the total noise increments, the development of the changed version NPD, and the evaluation of the changed version certification levels should be made using the procedures in paragraphs 2.3.4.12 and 2.3.4.13. Guidance material on confidence interval computations is provided in Appendix 1.

d) airframe design changes such as changes in fuselage length, flap configuration and engine installation, that could indirectly affect noise levels because of an effect on aeroplane performance (increased drag for example). Changes in aeroplane performance characteristics derived from aerodynamic analysis or testing have been used to demonstrate how these changes affect the aeroplane flight path and hence the demonstrated noise levels of the aeroplane.

In these cases care should be exercised to ensure that the airframe changes do not introduce significant new noise sources nor modify existing source generation or radiation characteristics. In such instances the magnitude of such effects may need to be established by test.

2.3 STATIC TESTS AND PROJECTIONS TO FLIGHT NOISE LEVELS

2.3.1 General

2.3.1.1 Static test evidence provides valuable definitive information for deriving the noise levels resulting from changes to an aeroplane powerplant or the installation of a broadly similar powerplant into the airframe following initial noise certification of the flight datum aeroplane. This involves the testing of both the flight datum and derivative powerplants using an open-air test facility whereby the effect on the noise spectra of the engine modifications in the aeroplane may be assessed. It can also extend to the use of component test data to demonstrate that the noise levels remain unchanged where minor development changes have been made.

2.3.1.2 Approval of equivalent procedures for the use of static test information depends critically upon the availability of an adequate approved data base (NPD plot) acquired from the flight testing of the flight datum aeroplane.

2.3.1.3 Static tests can provide sufficient additional data or noise source characteristics to allow a prediction to be made of the effect of changes on the noise levels from the aeroplane in flight.

2.3.1.4 Types of static test accepted for the purposes of certification compliance demonstration in aeroplane development include engine and component noise tests and performance testing. Such tests are useful for assessing the effects of mechanical and thermodynamic cycle changes to the engine on the individual noise sources.

2.3.1.5 Static engine testing is dealt with in detail in subsequent sections. The criteria for acceptance of component tests are less definable. There are many instances, particularly when only small EPNL changes are expected, that component testing provides an adequate demonstration of noise impact. These include, for example:

a) changes in the specification of sound absorbing linings within an engine nacelle;

b) changes in the mechanical or aerodynamic design of the fan, compressor or turbine;

c) changes to combustor designs; and

d) minor exhaust system changes.

2.3.1.6 Each proposal by the applicant to use component test data should be considered by the certificating authority with respect to the significance of the relevant affected source on the EPNL of the aeroplane.

2.3.2 **Limitation on the projection of static to flight data**

Details of the acceptability, use and applicability of static test data are contained in subsequent sections.

2.3.2.1 The amount by which the measured noise levels of a derivative engine will differ from the reference engine is a function of several factors, including:

a) thermodynamic changes to the engine cycle, including increases in thrust;

b) design changes to major components, e.g. the fan, compressor, turbine, exhaust system, etc.; and

c) changes to the nacelle.

2.3.2.2 Additionally, day-to-day and test site-to-site variables can influence measured noise levels and therefore the test, measurement and analysis procedures described in this manual are designed to account for these effects. In order that the degree of change resulting from aspects such as (a), (b) and (c) above, when extrapolated to flight conditions, are constrained to acceptable amounts before a new flight test is required, a limit is needed that can be used uniformly by certificating authorities.

2.3.2.3 The recommended guideline for this limit is that the summation of the magnitudes, neglecting signs, of the noise changes, for the three reference certification conditions, between the flight datum aeroplane and the derived version, at the same thrust and distance (for the derived version), is no greater than 5 EPNdB with a maximum of 3 EPNdB at any one of the reference conditions (see figure 5).

2.3.2.4 For differences greater than this additional flight testing at conditions where noise levels are expected to change is recommended to establish a new flight NPD data base.

2.3.2.5 Provided the detailed prediction procedures used are verified by flight test for all the types of noise sources, ie. tones, non-jet broadband and jet noise relevant to the aeroplane under consideration and there are no significant changes in installation effects between the aeroplane used for the verification of the prediction procedures and the aeroplane under consideration, the procedure may be employed without the limitations described above.

2.3.2.6 In addition to the limitations described above a measure of acceptability regarding methodologies for static to flight projection is also needed that can be used uniformly by certificating authorities. This measure can be derived as residual NPD differences between the flight test data and the projected static to flight data for the original aeroplane version. The guideline for a measure of acceptability is to limit these residuals to 3 EPNdB at any one of the reference conditions.

2.3.2.7 In the determination of the noise levels of the modified or derived version the same analytical procedures as used in the first static to flight calculations for the noise certification of the aeroplane type shall be used.

2.3.3 **Static engine tests**

2.3.3.1 *General*

2.3.3.1.1 Data acquired from static tests of engines of similar designs to those that were flight tested may be projected, when appropriate, to flight conditions and, after approval, used to supplement an approved NPD plot for the purpose of demonstrating compliance with the Annex 16, Volume 1, provisions in support of a change in type design. This section provides guidelines on static engine test data acquisition, analysis and normalisation techniques. The information provided is used in conjunction with technical considerations and the general guidelines for test site, measurement and analysis instrumentation, and test procedures provided in the latest version of the Society of Automotive Engineers (SAE) ARP 1846, "Measurement of Noise from Gas Turbine Engines During Static Operation". The engine designs and the test and analysis techniques to be used should be presented in the test plan and submitted, for approval, to the certificating authority for concurrence prior to testing. Note that test restrictions defined for flight testing in conformity with Annex 16, Volume 1, are not necessarily appropriate for static testing. (SAE ARP 1846 provides guidance on this subject).

2.3.3.1.2 For example, the measurement distances associated with static tests are substantially less than those encountered in flight testing and may permit testing in atmospheric conditions not permitted for flight testing by Annex 16, Volume 1. Moreover, since static engine noise is a steady sound pressure level rather than the transient noise level of a flyover, the measurement and analysis techniques may be somewhat different for static noise testing.

2.3.3.2 *Test site requirements*

The test site should meet at least the criteria specified in SAE ARP 1846. Different test sites may be selected for testing differing engine configurations provided the acoustic measurements from the different sites can be adjusted to a common reference condition.

2.3.3.3 *Engine inlet bell mouth*

The installation of a bell mouth forward of the engine inlet may be used with turbofan or turbojet engines during static noise tests. Such an installation is used to provide a simulated flight condition of inlet flow during static testing. Production inlet acoustic lining and spinners are also to be installed during noise testing.

2.3.3.4 *Inflow control devices*

2.3.3.4.1 The use of static engine test noise data for the noise certification of an aeroplane with a change of engine to one of a similar design requires the use of an approved Inflow Control Device (ICD) for high bypass engines (BPR > 2.0). The ICD should meet the following requirements:

a) The specific ICD hardware must be inspected by the certificating authority to ensure that the ICD is free from damage and contaminants that may affect its acoustic performance;

b) The ICD must be acoustically calibrated by an approved method (such as that provided in paragraph 2.3.3.4.3) to determine its effect on sound transmission in each one-third octave band;

c) Data obtained during static testing must be corrected to account for sound transmission effects that are caused by the ICD. The corrections shall be applied to each one-third octave band of data measured;

d) The ICD position relative to the engine inlet lip must be determined and the calibration must be applicable to that position; and

e) No more than one calibration is required for an ICD hardware design, provided that there is no deviation from the design for any one ICD serial number hardware set.

2.3.3.4.2 It is not necessary to apply the ICD calibration corrections if the same ICD hardware (identical serial number) is used as was previously used in the static noise test of the flight engine configuration, and the fan tones for both engines remain in the same one-third octave bands.

2.3.3.4.3 <u>ICD calibration</u>

An acceptable ICD calibration method is as follows:

a) Place an acoustic driver(s) on a simulated engine centreline in the plane of the engine inlet lip. Locate the calibration microphones on the forward quadrant azimuth at a radius between 50 ft and 150 ft that provides a good signal-to-ambient noise ratio and at each microphone angle to be used to analyse static engine noise data. Locate a reference near-field microphone on the centreline of and within 2 ft of the acoustic centre of the acoustic driver(s);

b) Energise the acoustic driver with pink noise without the ICD in place. Record the noise for a minimum of 60 s duration following system stabilisation. The procedure must be conducted at a constant input voltage to the acoustic driver(s);

c) Repeat item (b), alternately with and without the ICD in place. A minimum of three tests of each configuration (with and without ICD in place) is required. To be acceptable, the total variation of the 55° microphone on-line OASPL signal (averaged for a 1 minute duration) for all three test conditions of each configuration shall not exceed 0.5 dB;

Note: Physically moving the ICD alternately in and out of place for this calibration may be eliminated if it is demonstrated that the ICD positioning does not affect the calibration results.

d) All measured data are to be corrected for sound pressure level variations as measured with the near-field microphone and for atmospheric absorption to 77°F and 70 per cent RH conditions using the slant distance between the outer microphones and the acoustic driver(s);

e) The calibration for each one-third octave band at each microphone is the difference between the average of the corrected SPL's without the ICD in place and the average of the corrected SPL's with the ICD in place; and

f) The tests must be conducted under wind and thermal conditions that preclude acoustic shadowing at the outer microphones and weather induced variations in the measured SPL data. Refer to Figure 6, Section 2.3.3.7.

In some cases large fluctuations in the value of the calibrations across adjacent 1/3 octave bands and between closely spaced angular positions of microphones can occur. These fluctuations can be related to reflection effects caused by the calibration procedure and care must be taken to ensure that they do not introduce or suppress engine tones. This may be done by comparing effective perceived noise levels computed with:

a) the ICD calibrations as measured;

b) a mean value of the calibration curves; and

c) the calibration values set to zero.

2.3.3.5 *Measurement and analysis*

Measurement and analysis systems used for static test, and the modus operandi of the test programme, may well vary according to the specific test objectives, but in general they should conform with those outlined in SAE ARP 1846. Some important factors to be taken into account are highlighted in subsequent sections.

2.3.3.6 *Microphone locations*

2.3.3.6.1 Microphones should be located over an angular range sufficient to include the 10 dB-down times after projection of the static noise data to flight conditions. General guidance in SAE ARP 1846, describing microphone locations is sufficient to ensure adequate definition of the engine noise source characteristics.

2.3.3.6.2 The choice of microphone location with respect to the test surface depends on the specific test objectives and the methods to be used for data normalisation. Certification experience with static engine testing has been primarily limited to microphone installations near the ground or at engine centreline height. In general, because of the difficulties associated with obtaining free-field sound pressure levels that are often desirable for extrapolating to flight conditions, near-ground-plane microphone installations or a combination of ground-plane and elevated microphones have been used. Consistent microphone locations, heights, etc. are recommended for noise measurements of both the prior approved and changed version of an engine or nacelle.

2.3.3.7 *Acoustic shadowing*

2.3.3.7.1 Where ground plane microphones are used, special precautions are necessary to ensure that consistent measurements, e.g. free from "acoustic shadowing" (refraction) effects, will be obtained. When there is a wind in the opposite direction to the sound wave propagating from the engine, or when there is a substantial thermal gradient in the test arena, refraction can influence near ground plane microphone measurements to a larger degree than measurements at greater heights.

2.3.3.7.2 Previous evidence, or data from a supplemental test, may be used to demonstrate that testing at a particular test site results in consistent measurements, including the absence of shadowing. In lieu of this evidence, a supplemental noise demonstration test should include an approved method to indicate the absence of shadowing effects on the ground plane measurements.

2.3.3.7.3 The following criteria are suggested for certain test geometries, based on measurements of three weather parameters as follows:

-average wind speeds at engine centreline height (WCL);

-air temperature at engine centreline height (TCL); and

-air temperature near ground plane microphone height (TMIC).

a) The instruments for these measurements should be co-located and placed close to the 90° noise measurement position without impeding the acoustic measurement;

b) The suggested limits are additional to the wind and temperature limits established by other criteria (such as the maximum wind speed at the microphone if wind screens are not used); and

c) Wind and temperature criteria that have been observed to provide consistent measurements that preclude any influence of acoustic shadowing effects on ground plane measurements are defined in Figure 6.

The line defines a boundary between the absence of shadowing and the possible onset of spectral deficiencies in the very high frequencies. Testing is permitted provided that the test day conditions are such that the average (typically 30 s) wind speed at engine centreline height falls below the line shown, and that wind gusting does not exceed the value of the line shown by more than 5.5 km/h (3 kt). Wind speeds in excess of the linear relationship shown, between 7 and 22 km/h (4 and 12 kt), may indicate the need to demonstrate the absence of spectral abnormalities, either prior to or at the time of test when the wind direction opposes the direction of sound propagation.

When the temperature at the ground microphone height is not greater than the temperature at the engine centreline height plus 4° K, shadowing effects due to temperature gradients can be expected to be negligible.

Note: Theoretical analyses and the expression of wind criteria in terms of absolute speed rather than the vector reduction suggest that the noted limits may be unduly stringent in some directions.

2.3.3.8 *Engine power test conditions*

A range of static engine operating conditions should be selected to correspond to the expected maximum range of in-flight engine operating conditions for the appropriate engine power setting parameter. A sufficient number of stabilised engine power settings over the desired range should be included in the test to ensure that the 90 per cent confidence intervals in flight projected EPNL can be established (see paragraph 3 of Appendix 1 to this manual).

2.3.3.9 *Data system compatibility*

2.3.3.9.1 ~~The data acquisition and analysis systems should comply with he recommendations given in SAE ARP 1846.~~ If more than one data acquisition system and/or data analysis system is used for the acquisition or analysis of static data, compatibility of the ~~two~~ airframe and engine manufacturers' systems is necessary. ~~and~~ Compatibility of the data acquisition systems can be accomplished through appropriate calibration. Compatibility of the data analysis systems can be verified by analysing the same data samples on both systems. The systems are compatible if the resulting differences are no greater than 0.5 EPNdB. Evaluation should be conducted at flight conditions representative of those for certification.

2.3.3.9.2 The use of pseudo random noise signals with spectral shape and tonal content representative of turbo-fan engines is an acceptable alternative to using actual engine noise measurements for analysis system compatibility determination. The systems are compatible if the resulting differences are no greater than 0.5 PNdB for an integration time of 32 seconds. ~~The analysis system differences should be adjusted on a one-third octave basis.~~

2.3.3.10 *Data acquisition, analysis and normalisation*

For each engine power setting designated in the test plan, the engine performance, meteorological and sound pressure level data should be acquired and analysed using instrumentation and test procedures described in SAE ARP 1846. Sound measurements should be normalised to consistent conditions and include 24 1/3-octave band sound pressure levels between band centre frequencies of 50 Hz to 10 kHz for each measurement (microphone) station. Before projecting the static engine data to flight conditions, the sound pressure level data should be corrected for:

a) the frequency response characteristics of the data acquisition and analysis system; and

b) contamination by background ambient or electrical system noise. (See Appendix 3).

2.3.4 **Projection of static engine data to aeroplane flight conditions**

2.3.4.1 *General*

2.3.4.1.1 The static engine sound pressure level data acquired at each angular location should be analysed and normalised to account for the effects identified in 2.3.3.8. They should then be projected to the same aeroplane flight conditions used in the development of the approved NPD plot.

2.3.4.1.2 As appropriate, the projection procedure includes:

a) effects of source motion including Doppler effects;

b) number of engines and shielding effects;

c) installation effects;

d) flight geometry;

e) atmospheric propagation, including spherical wave divergence and atmospheric attenuation; and

f) flight propagation effects including ground reflection and lateral attenuation. (See paragraph 2.3.4.11).

2.3.4.1.3 To account for these effects, the measured total static noise data should be analysed to determine contributions from individual noise sources. After projecting the 1/3 octave-band spectral data to flight conditions, Effective Perceived Noise Levels should be calculated for the revised NPD plot. Guidelines on the elements of an acceptable projection procedure are provided in this section. The process is also illustrated in Figs 7 and 8.

2.3.4.1.4 It is not intended that the procedure illustrated in Figs 7 and 8 should be exclusive. There are several options, depending upon the nature of the powerplant noise sources and the relevance of individual noise sources to the Effective Perceived Noise Level of the aeroplane. The method presented does, however, specify the main features that should be considered in the computational procedure.

2.3.4.1.5 It is also not necessary that the computations should always be carried out in the order specified. There are interrelations between the various steps in the procedure which depend on the particular form of the computation being followed. Hence the most efficient manner of structuring the computation cannot always be pre-determined.

2.3.4.1.6 There are several engine installation effects which can modify the generated noise levels but which cannot be derived from static tests. Additional noise sources such as jet/flap or jet/wind interaction effects may be introduced on a derived version of the aeroplane which are not present on the flight datum aeroplane. Far-field noise directivity patterns (field shapes) may be modified by wing/nacelle or jet-by-jet shielding, tailplane and fuselage scattering or airframe reflection effects. However, general methods to adjust for these effects are not yet available. It is therefore important that, before the following procedures are approved for the derived version of the aeroplane, the geometry of the airframe and engines in the vicinity of the engines be shown to be essentially identical to that of the flight datum aeroplanes so that the radiated noise is essentially unaffected.

2.3.4.2 *Normalisation to reference conditions*

2.3.4.2.1 The analysed static test data should be normalised to freefield conditions in the Annex 16, Volume 1 reference atmosphere. This adjustment can only be applied with a knowledge of the total spectra being the summation of all the noise source spectra computed as described in paragraphs 2.3.4.3 to 2.3.4.5.

2.3.4.2.2 The required adjustments include:

a) *Atmospheric absorption*: adjustments to account for the acoustical reference day atmospheric absorption are defined in SAE ARP 866A (revised 15th March 1975). In the event that minor differences in absorption values are found in SAE ARP 866A between equations, tables or graphs, the equations should be used.

   The atmospheric absorption should be computed over the actual distance from the effective centre of each noise source to each microphone, as determined in 2.3.4.5; and

b) *Ground reflection*: examples of methods for obtaining freefield sound pressure levels are described in SAE AIR 1672B-1983 or Engineering Sciences Data Unit, ESDU Item 80038 Amendment A.

   Spatial distribution of noise sources do not have a first order influence on ground reflection effects and hence may be disregarded. It is also noted that measurements of far-field sound pressure levels with ground-plane microphones may be used to avoid the large spectral irregularities caused by interference effects at frequencies less than 1 kHz.

2.3.4.3 *Separation into broadband and tone noise*

2.3.4.3.1 The purpose of procedures described in this section is to identify all significant tones in the spectra, firstly to ensure that tones are not included in the subsequent estimation of broadband noise, and secondly to enable the Doppler-shifted tones (in-flight) to be allocated to the correct 1/3 octave band at appropriate times during a simulated aeroplane flyover.

2.3.4.3.2 Broadband noise should be derived by extracting all significant tones from the measured spectra. One concept for the identification of discrete tones is that used in Annex 16, Volume 1, Chapter 3 (Appendix 2) for tone correction purposes (that is, considering the slopes between adjacent 1/3 octave band levels). Care must be taken to avoid regarding tones as "non protrusive" when the surrounding broad band sound pressure level is likely to be lower when adjusted from static to flight conditions, or classifying a closely grouped pair, or series, of tones as broadband noise. One technique for resolving such problems is the use of narrow band analysis with a bandwidth of less than 50 Hz.

2.3.4.3.3 Narrow band analysis can also be used to check the validity of other tone identification procedures in establishing the spectral character at critical locations in the sound field, e.g. around the position of peak PNLT, or where predominant turbo-machinery tones exist.

2.3.4.4 *Separation into contributing noise sources*

2.3.4.4.1 The number of noise sources which require identification will to some extent depend on the engine being tested and the nature of the change to the engine or nacelle. Separation of broadband noise into the combination of noise generated by external jet mixing and by internal noise sources is the minimum and sometimes adequate requirement. A more sophisticated analysis may be necessary depending upon the significance of the contribution from other individual sources, which could involve identifying broadband noise from fan, compressor, combustor and turbine. Furthermore, for fan and compressor noise, the split of both the broadband and the tone noise between that radiating from the engine intake and that from the engine exhaust nozzle(s) could be a further refinement.

2.3.4.4.2 To meet the minimum requirement, separation of sources of broadband noise into those due to external jet mixing and those generated internally can be carried out by estimating the jet noise by one or more of the methods identified below, and adjusting the level of the predicted spectrum at each angle to fit the measured low frequency part of the broadband spectrum at which jet noise can be expected to be dominant.

2.3.4.4.3 There are three means which have been used to obtain predicted jet noise spectra shapes:

a) For single-stream engines with circular nozzles the procedure detailed in SAE ARP 876C-1985 may be used. However, the engine geometry may possess features which can render this method inapplicable. Example procedures for co-axial flow engines are provided in SAE AIR 1905-1985;

b) Analytical procedures based on correlating full scale engine data with model nozzle characteristics may be used. Model data have been used to supplement full scale engine data, particularly at low power settings, because of the uncertainty in defining the level of jet noise at the higher frequencies where noise from other engine sources may make a significant contribution to the broadband noise; and

c) Special noise source location techniques are available which, when used during full-scale engine tests, can identify the positions and levels of separate engine noise sources.

2.3.4.5 *Noise source position effects*

2.3.4.5.1 Static engine noise measurements are often made at distances at which engine noise sources cannot be truly treated as radiating from a single acoustic centre. This may not give rise to difficulties in the extrapolation to determine the noise increments from static data to flight conditions because noise increments in EPNL are not particularly sensitive to the assumption made regarding the spatial distribution of noise sources.

2.3.4.5.2 However, in some circumstances (for example, where changes are made to exhaust structures, and the sources of external jet-mixing noise are of overriding significance) it may be appropriate to identify noise source positions more accurately. The jet noise can be considered as a noise source distributed downstream of the engine exhaust plane. Internal sources of broadband engine noise may be considered as radiating from the intake and the exhaust.

2.3.4.5.3 There are three principal effects to be accounted for as a consequence of the position of the noise source differing from the "nominal" position assumed for the "source" of engine noise:

a) *Spherical divergence*: the distance of the source from the microphone differs from the nominal distance; an inverse square law adjustment needs to be applied.

b) *Directivity*: the angle subtended by the line from the source to the microphone and the source to the engine centreline differs from the nominal angle; a linear interpolation should be made to obtain data for the proper angle.

c) *Atmospheric attenuation*: the difference between the true and the nominal distance between the source and the microphone alters the allowance made for atmospheric attenuation in paragraph 2.3.4.2 above.

2.3.4.5.4 Source position can be identified either from noise source location measurements (made either at full or model scale), or from a generalised data base.

Note: No published standard on coaxial jet noise source distribution is currently available. An approximate distribution for a single jet is given by the following equation (see References 1 and 2):

$$x/D = \left(0.057S + 0.021S^2\right)^{-1/2}$$

where: S is the Strouhal number fD/V_j *;*

x is the distance downstream from the nozzle exit;

D is the nozzle diameter based on total nozzle exit area;

V_j *is the average jet velocity for complete isentropic expansion to ambient pressure from average nozzle-exit pressure and temperature; and*

f is the 1/3 octave band centre frequency.

2.3.4.6 *Engine flight conditions*

2.3.4.6.1 Some thermodynamic conditions within an engine tested statically differ from those that exist in flight and account should be taken of this. Noise source strengths may be changed accordingly. Therefore, values for key correlating parameters for component noise source generation should be based on the flight condition and the static data base should be entered at the appropriate correlating parameter value. Turbo-machinery noise levels should be based on the inflight corrected rotor speeds $N_1/\sqrt{q_{t_2}}$ and jet noise levels should be based on the relative jet velocities that exist at the flight condition.

2.3.4.6.2 The variation of source noise levels with key correlating parameters can be determined from the static data base which includes a number of different thermodynamic operating conditions.

2.3.4.7 *Noise source motion effects*

The effects of motion on jet noise differ from speed effects on other noise sources, and hence are considered separately during static-to-flight projection.

2.3.4.7.1 External jet noise

Account should be taken of the frequency-dependent jet relative velocity effects and convective amplification effects. Broadly, two sources of information may be used to develop an approved method for defining the effect of flight on external jet noise:

a) For single-stream engines having circular exhaust geometries, SAE ARP 876C-1985 provides guidance. However, additional supporting evidence may be needed to show when jet noise is the major contributor to the noise from an engine with a more complex nozzle assembly; and

b) Full scale flight data on a similar exhaust geometry can provide additional evidence. In general, however, because of the difficulty of defining high frequency effects in the presence of internally-generated engine noise, it may be necessary to provide additional supporting information to determine the variation of EPNL, with changes of jet noise spectra at high frequencies.

2.3.4.7.2 <u>Noise sources other than jet noise</u>

In addition to the Doppler frequency effect on the non-jet noise observed on the ground from an aeroplane flyover, the noise generated by the engine's internal components and the airframe can be influenced by source amplitude modification, and directivity changes:

a) *Doppler Effect*: frequency shifting that results from motion of the source (aeroplane) relative to a microphone is accounted for by the following equation:

$$f_{flight} = \frac{f_{static}}{(1 - M\cos l)}$$

where: f_{flight} = flight frequency;

f_{static} = static frequency;

M = Mach number of aeroplane; and

l = angle between the flight path in the direction of flight and a straight line connecting the aeroplane and the microphone at the time of sound emission.

It should be noted for those 1/3 octave band sound pressure levels dominated by a turbo-machinery tone, the Doppler shift may move the tone (and its harmonics) into an adjacent band.

b) *Source amplitude modification and directivity changes*: sound pressure level adjustments to airframe generated noise that result from speed changes between the datum and derivative version is provided for in paragraph 2.3.4.9, Airframe noise.

For noise generated internally within the engine, e.g. fan noise, there is no consensus of opinion on the mechanisms involved or a unique adjustment method that accounts for the detailed source modification and sound propagation effects.

If an adjustment is used, the same technique must be applied to both the flight datum and derivative configuration when establishing noise changes. In such instances the adjustment for sound pressure level changes that result form the motion of the source (aeroplane) relative to the microphone may be accounted for using the equation:

$$SPL_{flight} = SPL_{static} - K\log(1 - M\cos l)$$

where SPL_{flight} = flight sound pressure level;

SPL_{static} = static sound pressure level; and

M and λ are defined above and K is a constant.

Theoretically K has a value of 40 for a point noise source but a more appropriate value may be obtained by comparing static and flight data for the flight datum aeroplane.

2.3.4.8 *Aeroplane configuration effects*

2.3.4.8.1 The contribution from more than one engine on an aeroplane is normally taken into account by adding 10 log N, where N is the number of engines, to each component noise source. However, it might be necessary to compute the noise from engines widely spaced on large aeroplanes particularly in the approach case if they include both underwing and fuselage mountings. The noise from the intakes of engines mounted above the fuselage is known to be shielded.

2.3.4.8.2 If engine installation effects change between the flight datum aeroplane and a derived version, account should be taken of the change on sound pressure levels which should be estimated according to the best available evidence.

2.3.4.9 *Airframe noise*

2.3.4.9.1 To account for the contribution of airframe noise, measured flight datum airframe noise on its own or combined with an approved airframe noise analytical model may be used to develop an airframe noise data base. The airframe-generated noise, which can be treated as a point source for adjustment purposes, is normalised to the same conditions as those of the other (engine) sources, with due account for the effects of spherical divergence, atmospheric absorption and airspeed as described in section 8 and 9 of Appendix 2 of Annex 16, Volume 1.

2.3.4.9.2 Airframe noise for a specific configuration varies with airspeed (see Reference 3) as follows:

$$\Delta SPL_{airframe} = 50\log\left(V_{REF}/V_{TEST}\right)$$

where V_{REF} is approved reference airspeed for the flight datum aeroplane; and

V_{TEST} is model or measured airspeed.

2.3.4.9.3 The above equation is also valid for adjustments to EPNL where an empirically derived coefficient replaces the coefficient 50 since that number may be somewhat configuration dependent. However, approval of the certification authority is required for values other than 50.

2.3.4.10 *Aeroplane flight path considerations*

When computing noise levels corresponding to the slant distance of the aeroplane in flight from the noise measuring point, the principal effects are spherical divergence (inverse square law adjustments from the nominal static distance) and atmospheric attenuation, as described in sections 8 and 9 of Appendix 2 of Annex 16, Volume 1. Further, account should be taken of the difference between the static engine axis and that axis in flight relative to the reference noise measuring points. The adjustments should be applied to the component noise source levels that have been separately identified.

2.3.4.11 *Total noise spectra*

2.3.4.11.1 Both the engine tonal and broadband noise source components in flight, as discussed earlier, together with the airframe noise and any installation effects, are summed on a mean-square pressure basis to construct the spectra of total aeroplane noise levels.

2.3.4.11.2 During the merging of broadband and tonal components consideration should be given to appropriate band-sharing of discrete frequency tones.

2.3.4.11.3 The effects of ground reflections must be included in the estimate of freefield sound pressure levels to simulate the sound pressure levels that would be measured by a microphone at a height of 1.2 m above a natural terrain. Information in SAE AIR 1672B-1983 or Engineering Science Data Unit, ESDU data item 80038 Amendment A may be used to apply adjustments to the freefield spectra to allow for flight measurements being made at 1.2 m (4 ft). Alternatively, the ground reflection correction can be derived from other approved analytical or empirically derived models. Note that the Doppler correction for a static source at frequency f_{static} applies to a moving (aeroplane) source at a frequency f_{flight} where $f_{flight} = f_{static}/(1 - M\cos l)$ using the terminology of 2.3.4.7.2(a).

2.3.4.11.4 This process is repeated for each measurement angle and for each engine power setting.

2.3.4.11.5 With regard to lateral attenuation, information in SAE AIR 1751-1981 applicable to the computation of lateral noise may be applied.

2.3.4.12 *EPNL computations*

For EPNL calculations, a time is associated with each extrapolated spectrum along the flightpath. (*NOTE: Time is associated with each measurement location with respect to the engine/aeroplane reference point and the aeroplane's true airspeed along the reference flight path assuming zero wind*). For each engine power setting and minimum distance, an EPNL is computed from the projected time history using the methods described in Annex 16, Volume 1, Appendices 1 and 2.

2.3.4.13 *Changes to noise levels*

2.3.4.13.1 An NPD plot can be constructed from the projected static data for both the original (flight datum) and the changed versions of the engine or nacelle tested. Comparisons of the noise v's engine power relationships for the two configurations at the same appropriate minimum distance, will determine whether or not the changed configuration resulted in a change to the noise level from an engine noise source. If there is a change in the level of source noise, a new in-flight aeroplane NPD plot can be developed by adjusting the measured original NPD plot by the amount of change indicated by the comparison of the static-projected NPD plots for the original and changed versions within the limitations specified in 2.3.2 for Effective Perceived Noise Level.

2.3.4.13.2 The noise certification levels for the derived version may be obtained by entering the NPD plots at the relevant reference engine power and distance.

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